Fitness Heart Rate Measurement using Face Videos

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Introduction

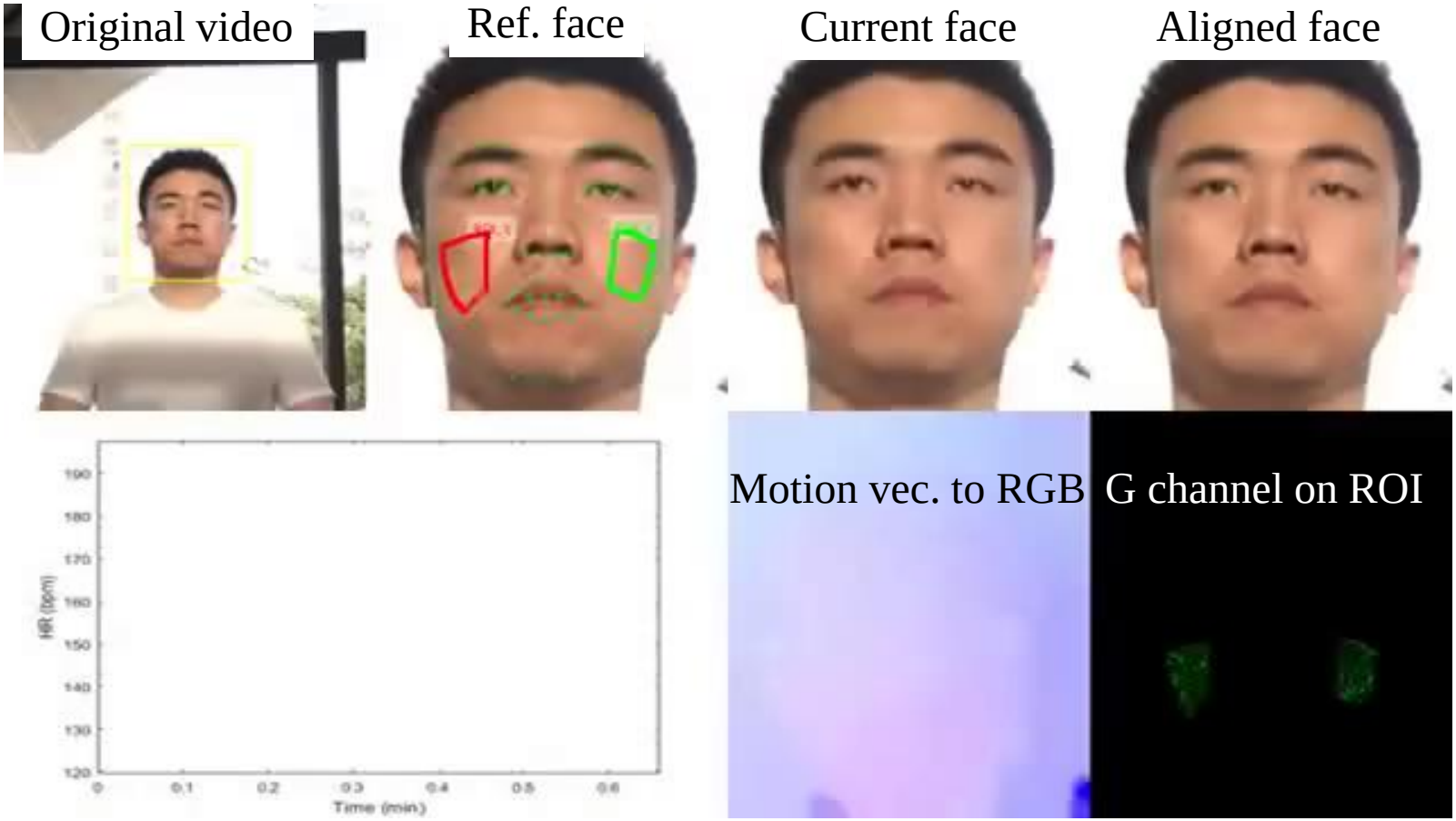
- Heart rate monitoring
  - Contact-based: chest belt, wrist band, ECG
  - Contact-free monitoring using video

    ~ Common in fitness exercise & care for special-needs

- Most works focused on rest/still case
- Addressing Challenges under significant subject motion:
  1. Reduce face registration error caused by fitness motion
  2. Separate heart beat micro signal from dominated motion modulated components
  3. Eliminate possible environmental illumination variation on face

Example Video

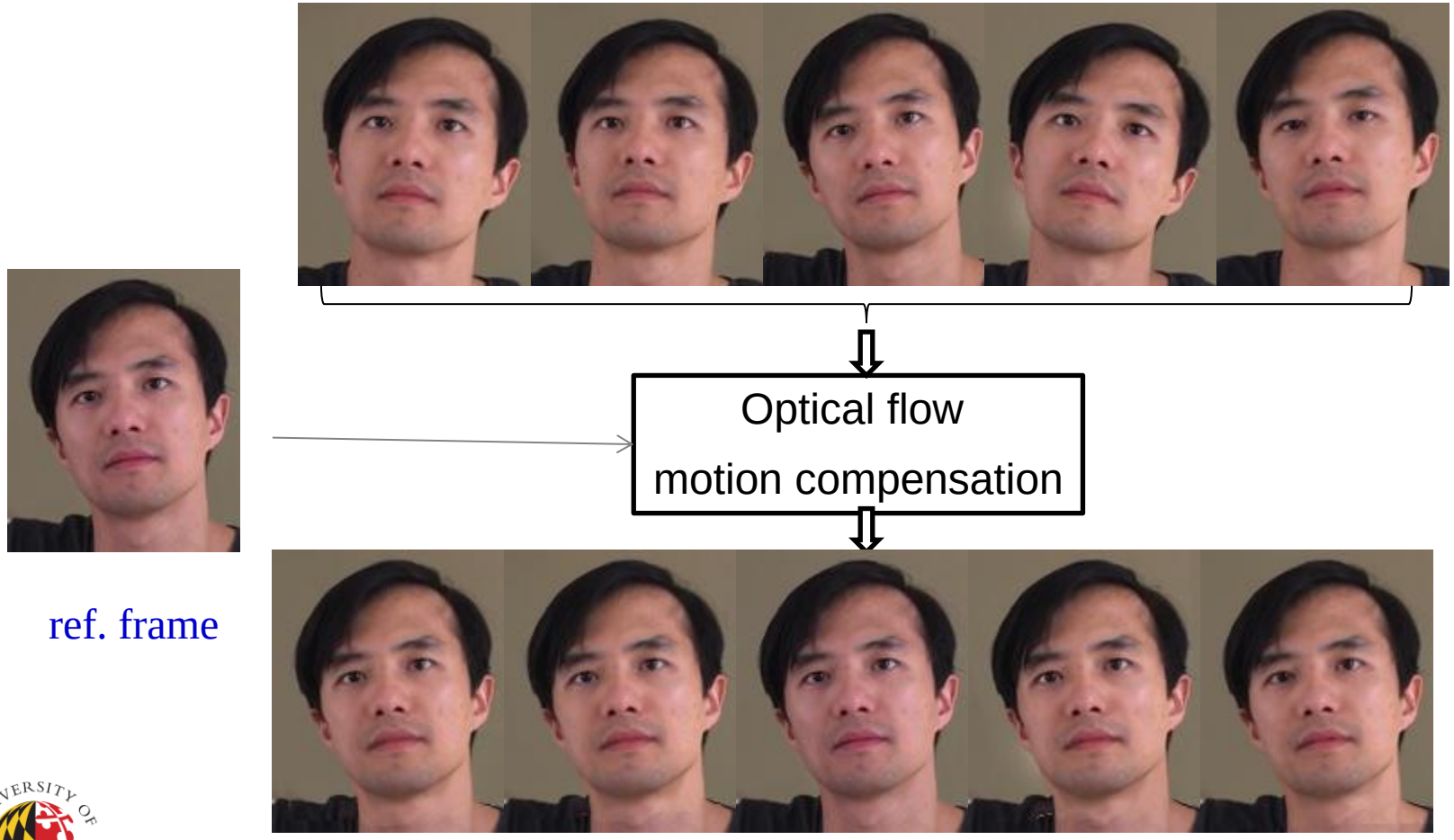
HR reference is from chest belt (gold standard for HR monitoring during fitness)



Face Registration (Single Ref.)

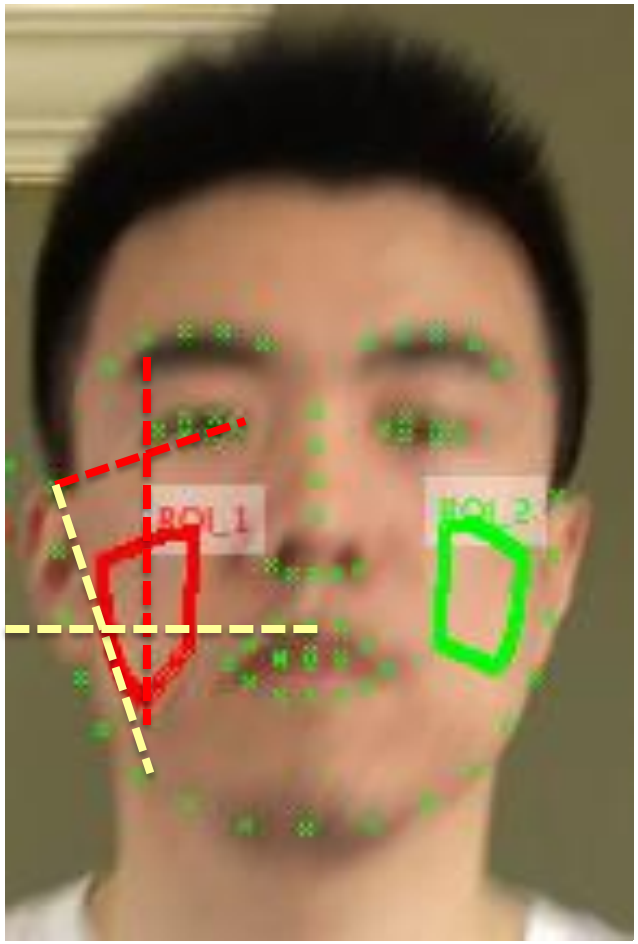
- ***Single Reference Solution***:

only use one reference frame to register entire video.



ROI (Cheek Region) Selection

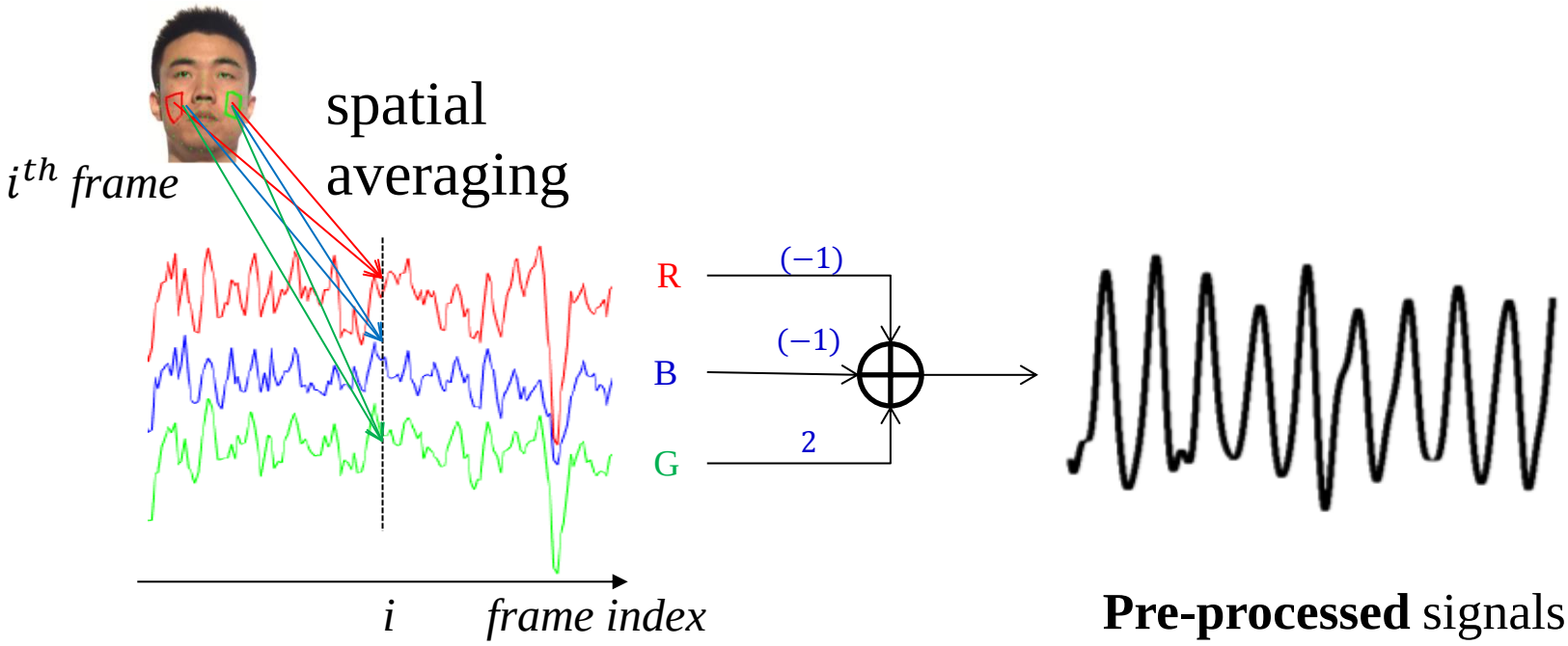
- Step 1: facial landmark localization
- Step 2: ROI central point
- Step 3: ROI defined by 20 landmarks (10 on each side) and central point



example of ROI selection on right cheek region

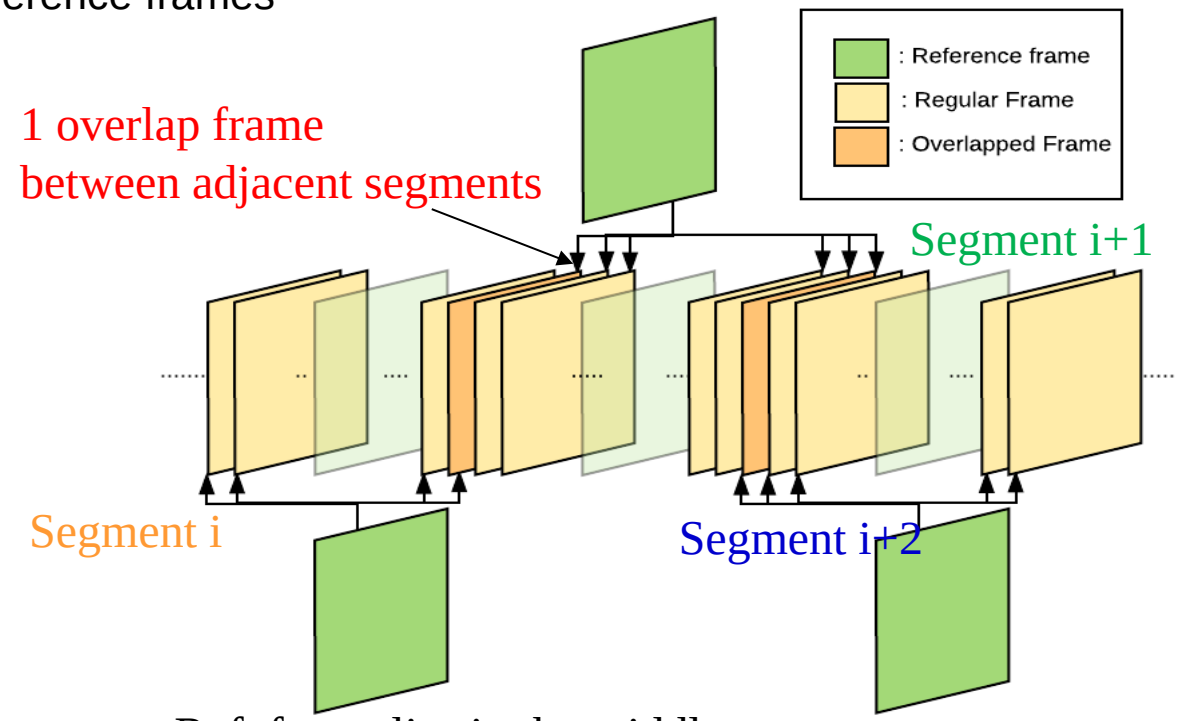
Face Color Signals

- Calculate face color signal by spatial averaging over Regions Of Interest (ROI)
- Obtain a linear combination of three color channels



Improved Segment-based Solution

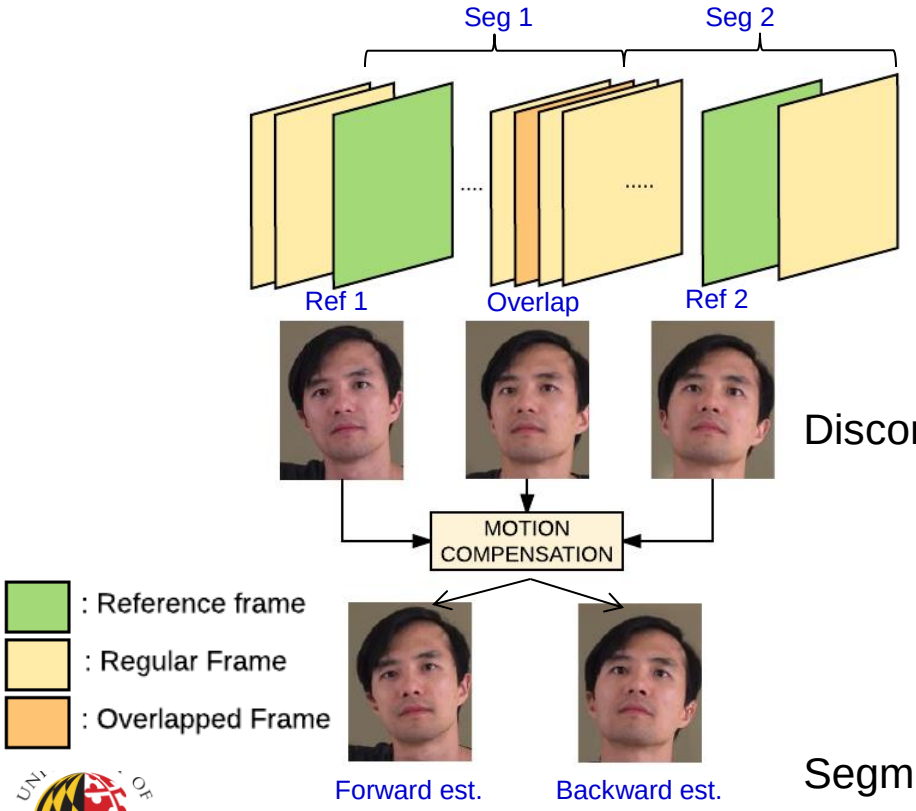
- Potentially significant occlusion due to long duration
- ***Improved Segment-based Solution***
  - Motivation: Bi-directional motion analysis used in advanced video coding technique
  - Motion compensation performs twice on overlapped frame w.r.t. two adjacent reference frames

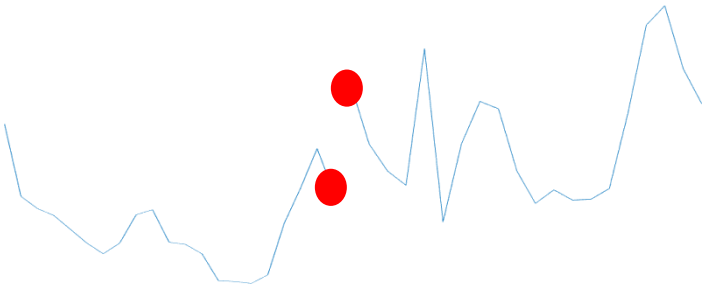


Segment Discontinuity

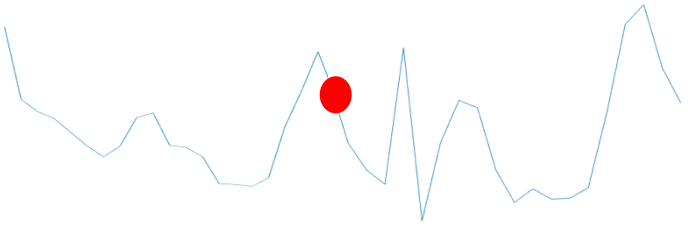
- *Segment Discontinuity Problem:*

Overlapped frame contributes different intensities as they correspond to same frame but with different reference.





Discontinuity on overlapped frame after spatial averaging



Segment aligned according to bias on overlapped frame

Detrending

- Slowly varying illumination trend is problematic
- Estimable with two assumptions:
  - *Assumption of Small Difference*:

    $\boldsymbol{L}_2$ distance between face color signal $\boldsymbol{x}_{raw}$ and trend $\boldsymbol{x}_{trend}$ of length L is small.
  - *Smoothness Assumption*:

    the accumulated convexity of the trend is small ------ensure smoothness of estimated trend signal.

$\boldsymbol{D}_2 \in \mathbb{R}^{L\times L}$: 2^{nd} order difference matrix

$$\hat{\boldsymbol{x}}_{trend} = \underset{\boldsymbol{x}}{\operatorname{argmin}} \underline{||\boldsymbol{x}_{raw} - \boldsymbol{x}||^2} + \lambda \underline{||\boldsymbol{D}_2 \boldsymbol{x}||^2}$$

Assumption of Small Difference *Smoothness Assumption*

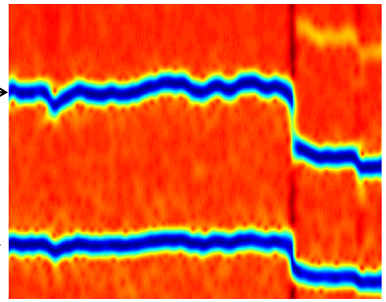
$$\Rightarrow \quad \hat{\boldsymbol{x}}_{trend} = (I + \lambda D_2^T D_2)^{-1} \boldsymbol{x}_{raw}$$

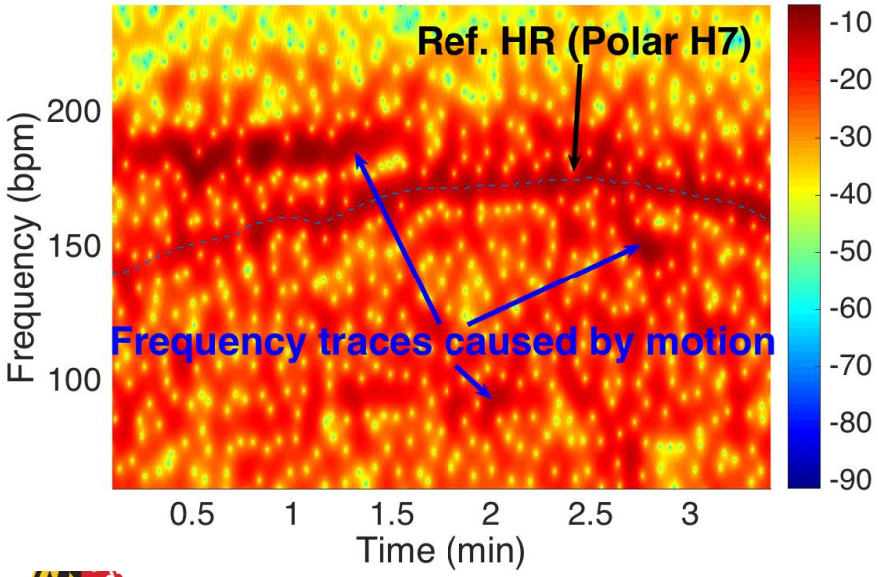
Motion Frequency Notching

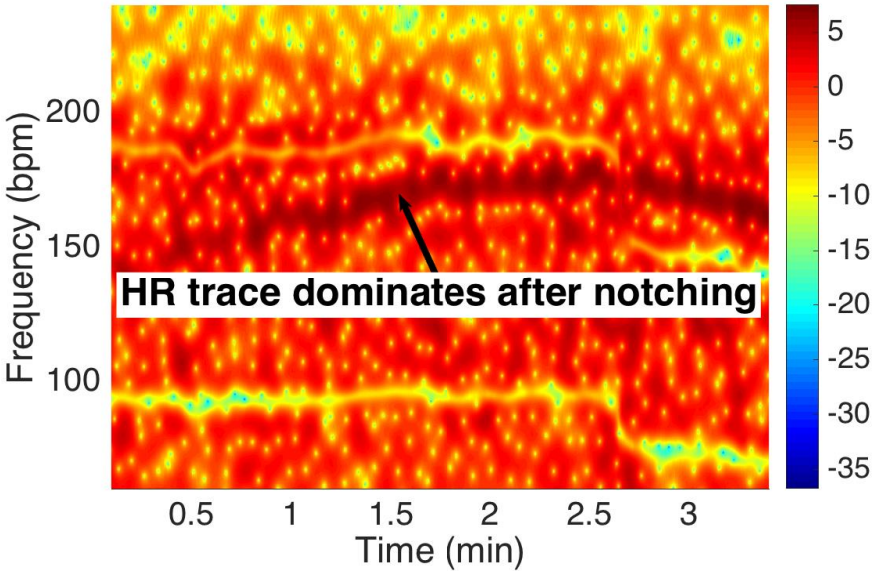
- Dominant frequency is notched s.t. the residue signal can have SNR improved w.r.t. heart rate to be estimated

Estimated frequency trace on x direction

Estimated frequency trace on y direction

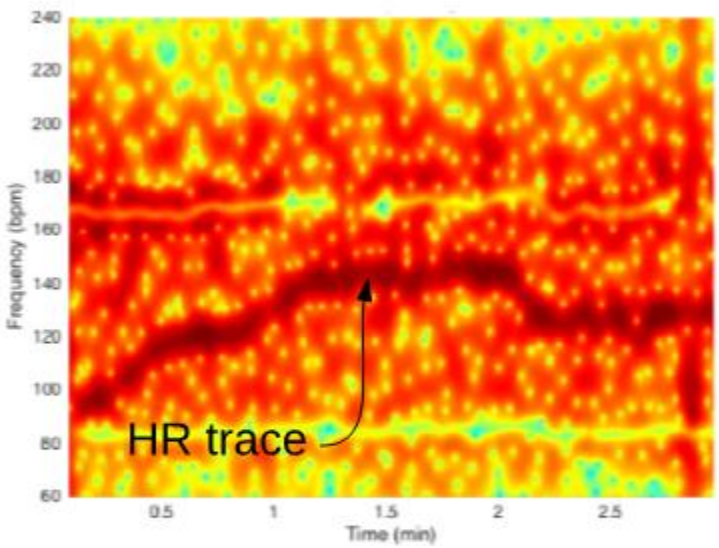




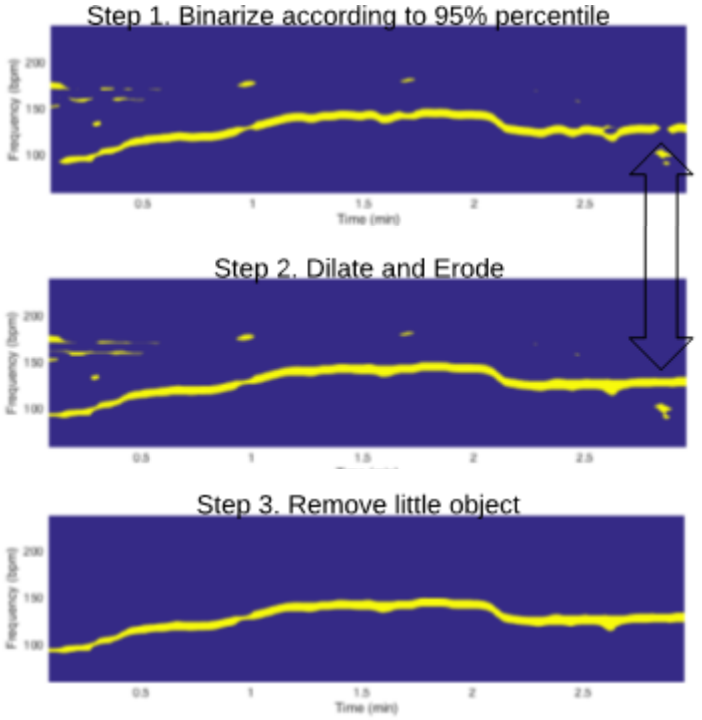


Robust Frequency Estimation

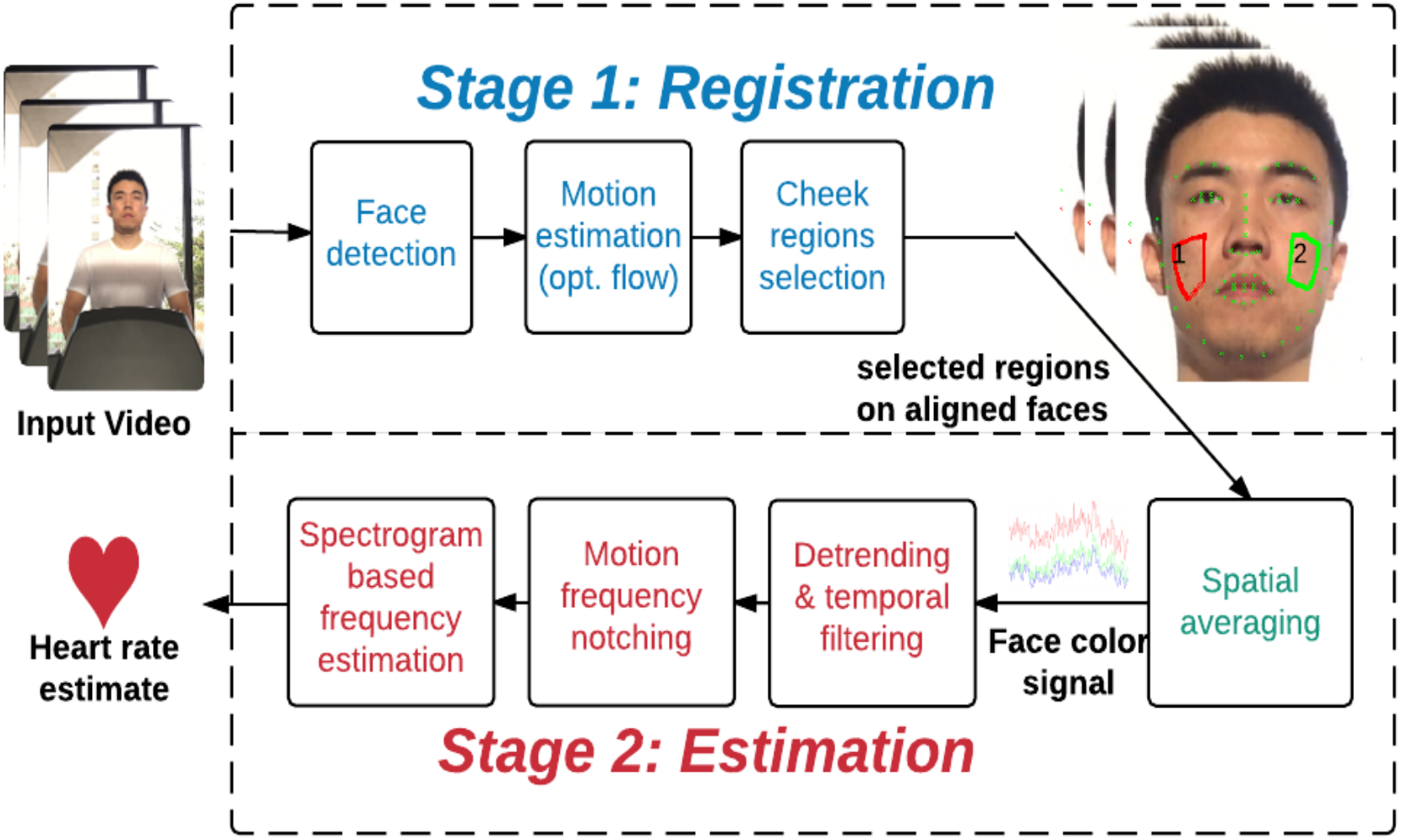
- First find the strap in spectrogram which corresponds to heart rate frequency component
- The heart rate is estimated by weighted averaging within the frequency range specified by the strap



Spectrogram of HR signal



Flow Chart of Proposed Method



Experiment Setting

Experiment setting	Details
Camera	IPhone6s rear camera
Video Length	≈3 mins
Frame Rate	30Hz
Lighting Condition	• Well lit • Over-the-top florescent lights • Diffused Daylight
Ref. HR measurement	Polar H7 chest belt (gold standard in athletic and fitness training)

System Performance

Module combination	RMSE in bpm (std)	M_{eRate} (std)
tracker+JBSS (no opt)	7.6 (5.7)	3.60% (2.87%)
tracker+fixed (no opt)	5.6 (3.4)	2.61% (1.45%)
tracker+op+JBSS	1.3 (0.7)	0.65% (0.30%)
tracker+op+fixed (proposed)	1.1 (0.6)	0.58% (0.33%)

no op

JBSS

VS.

fixed

op

Module Name:

- tracker: face tracker and face clipping
- op: optical flow based motion compensation
- JBSS: Joint Blind Source Separation by optimized color combination
- fixed: Source Separation by fixed weight color combination

Summary

- **Our proposed system** can give accurate and robust heart rate estimation from videos with large subject motion
- **Face registration error** is minimized by performing optical flow based motion compensation
- **Micro signal containing heart rate** is well separated from dominant large motion components by color combination and frequency notching procedure
- **Illumination variation** is eliminated by temporal detrending operation